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A QUALITATIVE AND QUANTITATIVE STUDY OF WEBER'S ILLUSION¹

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I. INTRODUCTION

In 1834 E. H. Weber described a tactual illusion which now bears his name.² When compass-points, kept equidistant, are moved with equal pressure over a cutaneous surface of varying sensitivity, the observer experiences a converging and a diverging of the two paths; a converging, when the points pass

¹ From the Psychological Laboratory of Cornell University.

² E. H. Weber, *De pulsu resorptione auditu et tactu*, *Annotat. anatom. et physiol.*, 1834, 59-75; Tastsinn und Gemeingefühl, in Wagner's *Handwörterb. d. Physiol.*, 1848, III, 524 f; Ueber den Raumsinn und die Empfindungskreise in der Haut und im Auge, *Ber. d. Sächs. Ges. d. Wiss.*, 1852, 93 ff.

from an area of greater to one of less sensitivity, and a diverging when they pass from an area of less to one of greater sensitivity. Weber indicated, in some detail, the form of the illusion as found at twelve different regions of the body.

Although the occurrence of the illusion, since Weber's time, has often been verified, and although authors have not agreed as regards his explanation of it, the illusion has never received systematic study. It seems to involve not only differences in sensitivity of the skin, but also perception of movement on the skin, relative localization of two moving points, and estimation of the distance between these points. We do not know whether the illusion is found on all parts of the cutaneous surface, whether a discontinuous movement would produce it, what rate of movement is most adequate for it, etc.

It is, then, such a systematic study (with these suggestive problems before us) that we have undertaken. We have explored the entire bodily surface for the illusion, and we have compared our results with those of Weber. We have also undertaken a qualitative study of the various factors which condition the illusion, and a quantitative study by means of which we hoped to compare direct judgments of relative distance with the indirect judgments of the illusion. In our quantitative work we employed the method of equivalents, a method first used by Weber and Wundt, later worked out by Fechner, then improved by Camerer, and standardized as laboratory method by Titchener.³ It has recently received some criticism at the hands of Gemelli.⁴ We have, however, adopted Titchener's form of the method, in the hope of obtaining a set of results adequate to a critical examination from the methodological point of view.

II. QUALITATIVE EXPERIMENTS

A. *The Nature of the Illusion at Various Regions of the Body*

The purpose of this part of our study was to explore the entire cutaneous surface for the illusion, and to obtain qualitative descriptions of the perceptive patterns which were aroused.

(a) *General Procedure.* The bodily surface was divided into forty-two regions; seven on the face, sixteen on the trunk, seven on the arm-hand, and twelve on the leg-foot. In the case of all bilateral parts, the left side or member was always arbitrarily chosen. These forty-two regions, which included the twelve described by Weber,

³ For a history of the method see E. B. Titchener, *Experimental Psychology*, ii, 1905, 191 ff.

⁴ A. Gemelli, *Il metodo degli equivalenti*, 1914.

were all explored by a single observer, and some of those which yielded the most clearly defined illusion were again explored by other observers. The instrument employed was the Griesbach aesthesiometer with hard rubber, slightly conical points, having a terminal diameter of 1.15 mm. The amount of pressure, which was approximately 19.5 gr. as measured on a chemical balance, was kept as nearly constant as possible. The three experimenters who took part in the experiment were practised in maintaining a uniform rate of movement; the average rate which obtained in a large majority of the experiments was 6.25 cm. per sec. The average rates for the two other experimenters were approximately 10 and 8 cm. The separations of the points of the aesthesiometer might, theoretically, be neither less than the two-point limen for the place of greatest sensitivity nor greater than the anatomical boundaries of the region to be examined. Within these limits, however, a considerable variation was possible; and since six experiments were made on every observer for a given region, various separations could be employed for every region. The actual separations used will be found in the tables. The directions of the parallel paths traced by the aesthesiometer were (1) longitudinal, *i.e.*, identical with or parallel to the median line of the trunk, face or limb; (2) horizontal, *i.e.*, at right angles to the median line; and (3) diagonal, *e.g.*, across the trunk from shoulder to hip. In the diagonal as also in the longitudinal directions the movement of the points was anterior-posterior on the face and trunk, and proximal-distal on the leg.

Wherever possible the observer, who was always blindfolded, reclined on a couch elevated by supports to a height of 1.2 m. This position allowed a free manipulation of the instrument, and secured the minimum of muscular tension on the part of the observer. The following kind of instruction was employed: "I am going to move a pair of compasses down the volar side of the left arm from near the shoulder to the finger-tips and I want you, immediately afterwards, to give an account of your experience. There will be the usual signals 'ready' and 'now.'" The observer's report was facilitated, at least once in a series on a given region, by an outline drawing of the region examined. Since the drawings served no other purpose than to aid the experimenter in obtaining accurate reports, they will not be included in our results.

The observers who took part in these experiments were Dr. C. A. Ruckmich (R), instructor in psychology, Mrs. L. D. Boring (Bo), instructor in psychology at Wells College, K. M. Dallenbach (D), J. S. Johnstone (J), and Miss J. N. Curtis (C), graduate students in psychology, Miss F. A. Bean (Be), an undergraduate majoring in psychology (Wellesley College), and the writer (G). Miss Colpitts served as experimenter when the writer was serving as observer.

(b) *Results.* Tables I-IV give the results of observer G, upon whom the entire forty-two regions were explored. The tables show the region examined, the number of cases, the actual separations in *mm.*, and include a brief description of the perceptive pattern. In the last column the numbers 1, 2, 3, etc., indicate the order of change in the relative direction of the two lines.

TABLE I

OBSERVER G. FACE

Number of cases for every region, 6

Region explored	Separations	Summary of results
I. Ear to ear over lips. Left to right.	25, 20, 15, 30, 20, 25	1. Gradually diverging to corner of lips. 2. Quickly diverging from there to center of lips. Illusion same on both sides.
II. Tongue; left margin, apex, right margin.	3, 2, 4, 2, 3, 3	Very slightly diverging on left margin to apex.*
III. Lower jaw; left to right ear. (One point on, the other beneath jaw.)	30, 25, 20, 35, 25, 20	Diverging from left ear to tip of chin. Right side corresponding.
IV. Forehead; right to left.	30, 25, 35, 20, 15, 25	Parallel.
V. Middle of forehead, down.	25, 20, 15, 30, 25, 20	Parallel.
VI. Left ear to just below clavicle; over middle of cheek and neck.	40, 35, 45, 50, 40, 45	1. Parallel or gradually converging on face. 2. Parallel on neck. (Distance less than "1".) 3. Parallel on chest. (Distance less than "2".)
VII. (A)—Center of lips to clavicle, over chin and neck.	35, 30, 30, 40, 25, 35	1. Gradually converging. Distance between initial and final distance very great.
(B)—Clavicle to center of lips, over neck and chin.†	35, 30, 30, 40, 25, 35	1. Parallel on neck to Adam's apple. 2. Then, diverging to lip. Distance between initial and final distance very great.

* Experimenter found it impossible to move compass over left margin satisfactorily, and so there is doubt of the accuracy of this report.

† This reverse direction was given on account of its mention by Weber.

TABLE II
OBSERVER G. TRUNK
Number of cases for every region, 6

Region explored	Separations	Summary of results
I. Across breasts; right to left.	55, 55, 60, 50, 45, 55	1. Parallel to right breast. 2. Diverging on right breast to nipple. 3. Converging, nipple to sternum; distance on sternum very small. Illusion same on left side.
II. Ventral side; right shoulder to left hip.	55, 50, 60, 55, 60, 55	Parallel, with slight decrease on breast-sternum regions.
III. Ventral side; half-way between median line and left side, clavicle to pelvic region.	50, 60, 65, 55, 45, 60	Parallel.
IV. Ventral side; median line, clavicle to pelvic region.	60, 55, 50, 45, 55, 55	1. Parallel to upper sternum. 2. Slightly converging on lower sternum. 3. Then slightly diverging. 4. Converging, lower pelvis.
V. Dorsal side; left to right shoulder. (Corresponding to breast region.)	50, 60, 65, 55, 60, 60	1. Doubtfully diverging to middle of shoulder blade. 2. Converging to spine; distance on spine less than on side. (Right side corresponds to left)
VI. Dorsal side; left shoulder to right hip.	60, 65, 60, 65, 75, 70	Parallel.
VII. Dorsal side, half-way between median line and left side; top of scapula to below waist.	60, 55, 65, 50, 65, 70	Parallel.
VIII. Dorsal side; half-way between median line and left side, waist over buttocks and upper leg to knee.	70, 75, 65, 80, 90, 75	Parallel, until about two-thirds distance between buttocks and knee; then gradually diverging to end.

TABLE II—*Continued*

OBSERVER G. TRUNK

Number of cases for every region, 6

Region explored	Separations	Summary of results
IX. Dorsal side, median line; neck to buttocks.	55, 60, 65, 60, 65, 65	1. Slightly diverging on neck and shoulder regions. 2. Then, parallel. 3. Slightly diverging near buttocks.
X. Around neck.	45, 30, 25, 30, 20, 25	1. Doubtfully parallel in front. 2. Diverging from right side to spine. 3. Thence converging to left side.
XI. Around trunk; level of shoulders.	50, 65, 60, 65, 55, 60	Parallel, with slight divergence across chest.
XII. Around trunk; level of lower ribs.	45, 40, 50, 45, 50, 45	1. Parallel on dorsal side. 2. Parallel—but distance greater—on ventral side.
XIII. Around trunk; level of waist.	60, 60, 55, 65, 55, 60	1. Parallel on dorsal side, slightly converging over spine. 2. Parallel on ventral side, diverging over ribs.
XIV. Around trunk; level of hips.	50, 55, 60, 45, 50, 55	1. Parallel on dorsal side. 2. Parallel, but distance greater on ventral side.
XV. Upper arm to hip; over volar side of arm, axilla, side.	60, 50, 55, 55, 60, 55	1. Parallel on upper arm. 2. Slightly diverging on axilla. 3. Diverging over ribs. 4. Converging to waist.
XVI. Left ear to elbow; neck, shoulder, upper arm (lateral) to elbow.	40, 45, 50, 50, 55, 55	1. Converging to clavicle. 2. Then parallel to elbow (slightly diverging twice from clavicle to end of shoulder).

TABLE III

OBSERVER G. ARM-HAND

Number of cases for every region, 6

Region explored	Separations	Summary of results
I. Lateral side; near top of upper arm to finger-tips.	45, 45, 40, 43, 45, 43	1. Parallel, upper arm. 2. Diverging on elbow. 3. Parallel, forearm (or slightly diverging toward waist). 4. Diverging, wrist. 5. Slightly converging, back of hand. 6. Slightly diverging, fingers.
II. Volar side; near top of upper arm to finger-tips.	35, 30, 35, 40, 40, 35	1. Parallel, upper arm. 2. Converging on elbow. 3. Gradually diverging to wrist, sometimes, parallel halfway down arm. 4. Then, slightly converging to palm. 5. Then, diverging to finger-tips.
III. Around upper arm, halfway between axilla and elbow.	50, 60, 45, 65, 40, 50	Parallel.
IV. Around elbow.	40, 50, 55, 60, 45, 50	Parallel.
V. Around forearm, halfway between elbow and wrist.	30, 35, 25, 40, 35, 40	Parallel.
VI. Around wrist.	15, 20, 25, 20, 25, 30	Parallel.
VII. Around hand.	20, 25, 30, 35, 20, 25	Parallel (distance once doubtfully less on dorsal side).

TABLE IV
OBSERVER G. LEG-FOOT
Number of cases for every region, 6

Region explored	Separations	Summary of results
I. Ventral side; near top of upper to middle of lower leg.	60, 55, 65, 45, 60, 55	1. Parallel on upper leg. 2. Gradually diverging on knee and lower leg.
II. Ventral side; middle of lower leg to end of toes.	35, 40, 30, 25, 30, 35	1. Parallel to vicinity of ankle. 2. Diverging over ankle. 3. Then slightly converging. 4. Then gradually diverging to end of toes.
III. Dorsal side; near top of upper to middle of lower leg.	50, 60, 65, 60, 65, 70	1. Parallel on upper leg. 2. Slightly converging on knee-joint. 3. Gradually diverging on lower leg (twice, parallel, but distance greater than in "2").
IV. Dorsal side; middle of lower leg, over heel and sole to toes.	20, 25, 30, 20, 15, 25	1. Fairly parallel to vicinity of ankle (here, it was very often just a band of pressure, distances of compass points limited to size of ankle). 2. Then diverging to near tip of heel. 3. Then parallel over sole (distance between paths less than in "2").
V. Lateral side; near top of upper leg to sole of foot.	60, 65, 55, 50, 60, 60	1. Parallel on upper leg. 2. Diverging on knee region. 3. Parallel (twice, parallel to only one-half or two-thirds distance to ankle; then gradually diverging). 4. Diverging over ankle. 5. Then slightly converging. 6. Then gradually diverging to sole.
VI. Median side; near top of upper to middle of lower leg.	65, 60, 55, 70, 75, 65	1. Parallel to or just below knee. 2. Then gradually diverging.

TABLE IV—*Continued*

OBSERVER G. LEG-FOOT

Number of cases for every region, 6

Region explored	Separations	Summary of results
VII. Median side; middle of lower leg, ankle and sole.	35, 25, 40, 30, 40, 35	1. Parallel to vicinity of ankle. 2. Gradually diverging to sole of foot. 3. Parallel.
VIII. Around upper leg; halfway to knee.	65, 60, 55 , 70, 50, 65	Parallel.
IX. Around knee.	35, 40, 30, 45, 20, 30	Parallel.
X. Around lower leg; halfway between knee and ankle.	40, 30, 45, 25, 35, 40	Parallel.
XI. Around leg above ankle.	30, 40, 35, 45, 30, 60	Parallel.
XII. Around foot.	25, 30, 20, 30, 15, 20	Parallel (sometimes doubtful whether distance on top of foot greater than on sole).

The tables show that the illusion is found in 55% (24 out of 42) of the regions examined. It occurs more frequently in the longitudinal than in the transverse direction; the ratio of occurrence to absence in the former direction is 15:3, in the latter, 8:11. The only regions where the illusion is found in the transverse direction are across the face, the tongue, around the trunk at the neck, the shoulders, the breasts, and waist. There are two places around the trunk, however, at the lower ribs and hips, where the two lines were perceived as parallel, but where the distances between them were greater on the ventral than on the dorsal side. These two cases we have regarded as doubtful.

The most marked illusions occur in the following regions: (1) ear to ear over lips; (2) lower jaw,—ear to ear; (3) centre of lips to clavicle; (4) across breasts; (5) upper arm to hip,—volar side of arm, axilla, side; (6) ventral side of trunk, median line; (7) lateral side of arm-hand; (8) volar side of arm-hand; (9) ventral side of leg-foot,—middle of lower leg to end of toes; (10) dorsal side of leg-foot,—middle of lower leg, over heel and sole; (11) lateral side of leg-foot; (12) median side of leg-foot,—middle of lower leg, over

ankle and sole. There is a close correspondence in the course of the illusion between corresponding parts of the arm-hand and leg-foot regions; but the illusion is more marked on the former.

(c) *Comparison with Weber's results.* The illusions as reported by G correspond for the most part with those mentioned by Weber for the same regions. The differences are given in Table V.

TABLE V

Region	Place of change	Weber's results	Our results
Across breasts.	From side to centre.	Diverging all the way.	Parallel to beginning of breast, then diverging.
Lateral side of trunk.	Over ribs from end of axilla.	Converging.	Diverging.
Same.	Between last rib and hip.	Diverging.	Converging.
Ventral side of trunk, median line.	Upper part of sternum.	Diverging.	Parallel.
Lower leg over calf to arch of foot.	Lateral side of leg—foot to arch.	Diverging.	(a) Parallel. (b) Diverging at ankle. (c) Converging. (d) Parallel.
Same.	Median side of leg—foot to arch.	Diverging.	(a) Parallel to vicinity of ankle. (b) Diverging to arch.
Trunk.	Around neck.	No regularity.	(a) Diverging on dorsal side to vertebral prominence. (b) Converging.

(d) *Experiments with Other Observers.* We selected several regions for exploration with other observers. The only changes in these experiments were an increase (in some instances) of the number of tests for certain regions, and a greater variation of the aesthesiometer separations. The results are given in Tables VI-IX.

TABLE VI
EAR TO EAR, OVER LIPS

Obs.	No. cases	Distances	Summary of results
Be	6	25, 20, 30, 25, 35, 30	Diverging to center of lips. Illusion the same on both sides of face.
Bo	6	25, 20, 30, 25, 35, 30	1. Parallel to corner of lips. 2. Diverging to center of lips. Same on both sides.
J	30	20, 23, 18, 10, 20, 19, 23, 25, 25, 30, 19, 20, 30, 19, 18, 28, 27, 25, 26, 26, 25, 20, 23, 25, 30, 30, 20, 12, 18, 19	1. Gradually diverging to corner of lips. 2. Quickly diverging to center of lips. Illusion the same on both sides of the face.

TABLE VII
VOLAR SIDE OF ARM-HAND

Obs.	No. cases	Distances	Summary of results
Bo	6	35, 40, 30, 45, 35, 40	1. Parallel or diverging on upper arm. 2. Converging at elbow. 3. Diverging to wrist.* 4. Converging at base of hand. 5. Diverging to end, or diverging to mounds then converging, then diverging or parallel.†
D	25	35, 10, 30, 33, 30, 30, 31, 35, 30, 25, 20, 20, 10, 40, 25, 25, 10, 40, 30, 35, 15, 25, 20, 15, 25	1. Parallel on upper arm. 2. Slightly converging at elbow. 3. Gradually diverging to wrist. 4. Converging to palm. 5. Diverging to mounds. 6. Parallel to finger-tips.
R	25	35, 15, 20, 20, 30, 30, 25, 20, 30, 20, 15, 40, 35, 30, 39, 35, 36, 20, 40, 32, 35, 15, 30, 20, 33	1. Parallel on upper arm. 2. Slightly converging at elbow. 3. Gradually diverging to wrist, or parallel to wrist then diverging. 4. Converging to middle of palm. 5. Diverging to finger-tips.

* Twice, a divergence followed by a convergence occurred between elbow and wrist.

† Once, divergence at base of hand, then convergence to palm, and divergence to finger-tips.

TABLE VIII

OBSERVER C. TRUNK

Number of cases for every region, 6

Region explored	Distances	Summary of results
Across breast.	50, 55, 45, 55, 60, 55	1. Converging to right breast. 2. Diverging on right breast to nipple. 3. Converging, nipple to sternum, distance on sternum very small. Illusion same on left side.
Across back—left to right shoulder (lower part).	55, 60, 65, 50, 55, 50	1. Diverging to middle of left shoulder blade. 2. Converging to spine; distance here very small. Illusion same on right side.
Upper arm to hip— over volar side of arm, axilla, side.	45, 40, 45, 45, 50, 55	1. Parallel on arm. 2. Diverging on axilla. 3. Parallel. 4. Converging at waist.
Around neck.	25, 30, 30, 25, 20, 30	1. Parallel on ventral side; twice diverging slightly to, and converging from, median line.
		2. Diverging to, and from, vertebral prominence. Amount of divergence greater than in "1".

TABLE IX

OBSERVER Bo. LEG-FOOT

Number of cases for each region, 6

Region explored	Distances	Summary of results
Dorsal side of leg: near top of upper to middle of lower.	65, 70, 60, 75, 70, 70	1. Parallel to point beyond knee-joint (twice, converging). 2. Slightly diverging to end.
Dorsal side of leg: middle of lower to toe.	30, 25, 40, 35, 30, 30	1. Parallel to near heel. (Once, divergence at beginning of ankle.) 2. Diverging to end. (Once, converging at instep: then diverging to end.)

A comparison of Tables VI-IX with Tables I-IV shows that, with the following exceptions, the illusions are the same for these observers as for G. (1) For Bo, the lines were parallel (instead of diverging) from ear to corner of lips; parallel (instead of converging) over knee-joint, dorsal side; and diverging (instead of parallel) over sole of foot. (2) For C, the paths were converging (instead of parallel) from side to breast, and parallel (instead of diverging and converging) over ribs from axilla to near waist. (3) For D, they were parallel (instead of diverging) on volar side of fingers. It will be noticed that in none of these cases is there a reversal of direction as regards convergence and divergence; and the general agreement of all observers, including Weber, bespeaks the stability of the illusion.

There is one respect, however, in which our results differ from Weber's; namely, in the effect on the illusion of two-point separations below the two-point limen. For example, Weber gives the value of the two-point threshold on the forearm as 40 mm. When the distances between the compass-points were from 16 to 25 mm., he found that the impression on the fore-arm was not that of two parallel lines but that of a single line which divided at the palm of the hand. When the distance was 40 mm., the impression was that of two parallel lines. In other words, the typical illusion fails in his case for distances considerably below the two-point limen.⁵ In our own experiments we have repeatedly employed distances on the fore-arm ranging from 10 to 40 mm., and we have never failed to obtain the illusion. Weber warns against what we now call the stimulus-error, and of course our observers were trained to avoid that. The only explanation we can offer for the difference of results is that Weber may have employed a pressure less than the 19.5 gr. of our experiments. We might perhaps expect the two-point limen for a moving stimulus to be less than that for an unmoved stimulus; but we know of no observations which cover this point.

B. *The Influence of Various Conditions on the Illusion*

The factors which we have investigated as conditioning the illusion are as follows: (a) the correspondence of certain of our qualitative results with differences of sensitivity in similar regions as measured by the two-point limen; (b) the continuity *vs.* the discontinuity of stimulation; (c) variation in the rate of movement of the stimulus; (d) the influence of visualization and eye-kinaesthesia on the illusion; (e) ease of localization of the stimulus, and variations in quality, intensity and clearness of the impressions; and (f) racial differences.

(a) *Correspondence between the Illusion at Certain Regions and Differences of Sensitivity at these Regions.* Vierordt has given sets of values showing differences of sensitivity at (1) the ventral-median line of head, neck, trunk, and leg; (2) the

⁵ E. H. Weber, *Ueber den Raumsinn*, 93 f.

dorsal-median line of the same parts; (3) the side line of the trunk; (4) the volar-side of the arm; and (5) the face. Weber has given detailed descriptions of variations in sensitivity of the cutaneous surface at various regions.⁶ We have utilised these descriptions by comparing them with our qualitative results. The following table shows the changes of the illusion as compared with-changes in sensitivity.

TABLE X

Region	Changes in Illusion	Changes in Sensitivity	
		Weber	Vierordt
I Ear to ear over lips.	1. Gradually diverging to corner of lips (or parallel). 2. Quickly diverging from corner to centre of lips. Illusion same on both sides.	1. Progressively greater. 2. Prog. greater.	1. Progressively greater. 2. Prog. greater.
II Lower jaw; ear to ear.	1. Diverging from ear to tip of chin. Illusion same on both sides.	1. Prog. greater.	1. Prog. greater.
III Centre of lips to clavicle.	1. Converging.	1. Prog. less.	1. Approximately equal. 2. Prog. less.
IV Across breasts.	1. Parallel to right breast (or converging). 2. Diverging on right breast to nipple. 3. Converging to sternum. Illusion same on left breast.	1. Prog. greater. 2. Prog. greater. 3. Prog. less.	

⁶ K. Vierordt, *Physiologie des Menschen*, 1877, 343-349; Weber, *De pulsus resorptione auditu et tactu*, l. c.

TABLE X—*Continued*

Region	Changes in illusion	Changes in sensitivity	
		Weber	Vierordt
V Upper arm to hip; volar side of arm, axilla, side.	1. Parallel on upper arm. 2. Diverging (slightly G) on axilla. 3. Diverging over ribs (or parallel). 4. Converging to waist.	1. Small difference. 2. Greater sensitivity? 3. Prog. less.* 4. Prog. greater.*	3. (a) less.* (b) greater. 4. Less.
VI Ventral side of trunk; median line.	1. Parallel on upper sternum. 2. Slightly converging on lower sternum. 3. Then slightly diverging. 4. Converging, lower pelvic region.	1. Prog. greater.* 2. Prog. less. 3. Prog. greater. 4. Prog. less.	1. Approx. equal. 2. Less. 3. Approx. equal. 4. Approx. equal.
VII Lateral side of arm-hand.	1. Parallel, upper arm. 2. Diverging, elbow. 3. Parallel fore-arm (or slightly diverging to waist). 4. Diverging at waist. 5. Slightly converging, back of hand. 6. Slightly diverging, fingers.	1. Approx. equal. 2. Greater. 3. Approx. equal, to near wrist. 4. Greater (greater than 2). 5. Less. 6. Greater.	
VIII Volar side of arm-hand.	1. Parallel, upper arm. 2. Converging, elbow-joint. 3. Gradually diverging to wrist; sometimes parallel halfway to wrist. 4. Then slightly converging to palm. 5. Then diverging to finger tips; or parallel.	1. Approx. equal. 2. Greater.* 3. Approx. equal; greater at wrist (greater there than at elbow.) 4. Prog. less. 5. Prog. greater.	1. Approx. equal. 2. Approx. equal. 3. Prog. greater. 4. Approx. equal. 5. Prog. greater.

* The asterisks indicate a non-correspondence of divergence with greater, and convergence with less, sensitivity.

TABLE X—*Continued*

Region	Changes in illusion	Changes in sensitivity	
		Weber	Vierordt
IX Ventral side of leg-foot—middle of lower leg, over foot.	1. Parallel to vicinity of ankle. 2. Diverging over ankle 3. Then slightly converging at instep. 4. Then, gradually diverging.	1. Approx. equal. 2. Greater. 3. Less. 4. Prog. greater.	1. Approx. equal. 2. Approx. equal. 3. Prog. greater.* 4. Prog. greater.
X Dorsal side of leg-foot—middle of lower leg, over heel and sole.	1. Fairly parallel to vicinity of ankle. 2. Then diverging to near tip of heel. 3. Then, parallel or diverging over sole.	1. Approx. equal. 2. Prog. greater. 3. Prog. less* to arch; then progressively greater to toes.	
XI Lateral side of leg-foot.	1. Parallel on upper leg. 2. Diverging, knee-region. 3. Parallel twice, parallel to only one-half or two-thirds distance to ankle, then gradually diverging. 4. Diverging over ankle 5. Then slightly converging. 6. Then gradually diverging on sole.	1. Approx. equal. 2. Greater. 3. Approx. equal. 4. Greater. 5. Less. 6. Equal?*	
XII Median side of leg-foot—middle of lower leg, over ankle and sole.	1. Parallel to vicinity of ankle. 2. Gradually diverging to sole. 3. Parallel.	1. Approx. equal. 2. Greater (then less?) 3. Approx. equal.	

* The asterisks indicate a non-correspondence of divergence with greater, and convergence with less, sensitivity.

It was Weber's belief that the illusion is directly conditioned upon change in sensitivity of the cutaneous surface. "Sie [die Bahnen] scheinen an den Teilen der Haut zu divergieren, wo die Hauttheile auf feiner fühlende übergehen, sie scheinen dagegen dann zu convergieren, wenn sie von feiner fühlenden Hauttheilen auf stumpfer fühlende übergehen." This position has been questioned by Lichtenfels, Wundt and Judd.⁷ Wundt lays it down as a general rule that the perception of local differences and the estimation of the distance between two impressions are independent; the illusion is therefore conditioned upon other factors. Judd bases his objection on results obtained by Camerer, who found, by the method of equivalents, that the same separations were occasionally judged as equal when the points were placed upon cutaneous surfaces of different sensitivity. Our results show however, that, with eight exceptions, an increase in sensitivity (according both to Weber and to Vierordt) corresponds with a divergence, a decrease with a convergence, while an "approximately equal" may correspond with divergence, convergence, or parallelism. This latter equivocal correspondence, taken together with the eight exceptions, points to other determining factors in the illusion, which we shall discuss later.

(b) *Continuity vs. discontinuity of movement.* Wundt mentions continuous movement of the stimulus as a condition of the illusion. This factor we have attempted to investigate as follows. We selected regions (explored in previous experiments) where the illusion was well defined; and we moved the stimulus over such a region, first continuously, and then after an interval of one second discretely, the stimulus being now moved for a short distance only over those places where the earlier results indicated a change in direction of the paths. The observers were instructed in both cases to report the impression perceived. We give a summary of the results of the discontinuous series in Table XI.

The table shows (1) that with discontinuous stimuli the illusion of converging and diverging paths practically never occurs; we find instead a series of short parallel paths which vary in amount of separation; and (2) that the relative magnitudes of the distances between the paths at the places of change are similar with discontinuous and with continuous movement. Where the continuous stimuli yield a convergence,

⁷ E. H. Weber, *Ueber den Raumsinn*, 93; R. Lichtenfels, *Sitzungsber. d. W. Akad.*, vi, 1851, 348 f.; W. Wundt, *Grundzüge*, ii, 1910, 465; C. H. Judd, *Philos. Stud.*, xii, 1896, 457; W. Camerer, *Zeit. f. Biol.*, xxiii, 1886, 509.

TABLE XI

Obs.	Region	Places of change on region	Results with Discrete Stimuli
Bo	I. Ear to ear over lips.	a b c d e	Paths parallel. Same, but distance less than at a. Same, but distance less than at b. Same, but distance less than at c. Same but distance equal to d.
	II. Volar side of arm-hand.	a b c d e	Paths parallel. Same, but distance less than at a. Same, but distance greater than at b.* Same, but distance less than at c. Same, but distance greater than at d.
	III. Dorsal side of leg near top of upper to middle of lower.	a b c	Paths parallel. Same, but distance less than at a. Same, but distance greater than at b.
	IV. Dorsal side of leg-foot; middle of lower leg to toes.	a b c	Paths parallel. Same, but distance greater than at a. Same, but distance greater than at b.
	V. Across breasts.	a b c	Paths divergent.† Paths parallel, but distance greater than a. Same, but distance less than at b.
	VI. Across back.	a b c	Paths parallel. Same, but distance greater than at a. Same, but distance less than at b.
C	VII. Upper arm to hip,—over volar side of arm, axilla, side.	a b c d	Paths parallel. Same, but distance greater than at a. Same, but distance less than at b. Same, but distance less than at c.
	VIII. Neck.	a b	Paths parallel. Same, but distance less than at a.

* Twice not parallel; (1) diverging, (2) diverging then converging.

† The discontinuous distances on this region were reported as very difficult to judge. Sometimes no judgments could be given, or only doubtful ones.

there the distance between the parallel paths is less than that at the preceding place in a region; and, conversely, where they yield a divergence, the distance is greater.

It appears, then, that short movements on the skin are sufficient for a perception of direction and relative distance, but that they do not permit the perception of a change in the direction of movement. This result is perhaps conditioned, in part at least, upon the fact, first observed by Hall and Donaldson,⁸ that a moving point on the skin must traverse a certain distance before a judgment of direction can be given. Since the points were put down near the place of change, the relative direction of the two paths would naturally be perceived as parallel; and before a change could be discriminated, the movement came to an end.

(c) *Variation in Rate of Movement of the Two-point Stimuli.* The authors who discuss the illusion do not agree as regards the optimal rate of movement. Halliburton and Ladd say that the compasses should be moved slowly, Schaefer 'with sufficient speed,' and Wundt, quickly.⁹ We repeated the experiment with two observers and at various regions with the following rates (cm. per sec.): 1.56, 3.13, 12.5 and 25. Since in the majority of our experiments we employed the rate of 6.25 cm. per sec, we can compare our former results with those of the new rates. We give the latter in Table XII.

It will be seen that none of the four rates employed in this group of experiments gives the illusion as consistently as the rate of 6.25 cm. per sec. There is also a rather wide individual variation. With the fastest rate Bo did not obtain the illusion; and at the other extreme, although the illusion was more marked, new variations appeared. C, on the other hand, finds the faster rate more favorable to the illusion than the slower. The fact that both observers find numerous irregularities, smaller convergences and divergences, etc., with the very slow rate, seems to suggest that some other factors which as a rule are not functioning in the illusion, such, *e.g.*, as differences in quality or of distinctness of impression, or perhaps visual imagery, may be operative. We return to this point later.¹⁰

(d) *Effect of Visualization: Experiments with Blind Observers.* All our observers reported that eye-movement and

⁸ G. S. Hall and H. H. Donaldson, *Motor Sensations of the Skin, Mind*, x, 1885, 563 ff.

⁹ W. D. Halliburton, *Handbook of Physiology*, 1911, 766; G. T. Ladd, *Elements of Physiological Psychology*, 1892, 406; E. A. Schaefer, *Text-book of Physiology*, 1911, 943; W. Wundt, *loc. cit.*

¹⁰ See pp. 118 f.

visual imagery were usually, if not invariably, present, in the perception of the illusion. Attempts under instruction to inhibit both kinaesthesia and imagery failed; partly because the effort itself failed, partly because the inhibition served as a distraction from the perception of the illusion. Only in one instance, when the *O* was allowed with open eyes to fixate an object, was there a pure tactual perception of moving points. The experience was not clear, however, and the direction and localization were indefinite.

TABLE XII

OBSERVER BO. INFLUENCE OF VARIOUS RATES OF MOVEMENT

Regions explored	Rates in cm. per sec.			
	25	12.5	3.13	1.56
I Ear to ear over lips.	Practically parallel; slight divergence to centre of lips.	Practically parallel; very slight divergence to centre of lips.	More marked? also paths bulged on centre of cheeks.	More marked; also paths bulged on centre of cheeks.
II Volar side of arm-hand.	Approximately parallel; a slight divergence near wrist; some variation on palm; slight convergence at elbow.	As average.	As average except no convergence at elbow.	More marked. Also, there were besides the usual convergences and divergences many smaller ones, succeeding each other incessantly.
III Dorsal side of leg—near top of upper to middle of lower.	Practically parallel.	As average.	As average.	More marked. Once, an extra divergence and convergence on lower leg.
IV Dorsal side of leg—middle of lower leg to toes.	Practically parallel.	As average.	More marked; extra changes noted: (1) convergence just below ankle; (2) convergence at instep.	More marked; two extra changes noted as with the faster rate.

OBSERVER C

I Across breasts	As average.	As average.	As average.	Paths crossed and recrossed (in one experiment 15 times); no regularity about the crossing or about the variations of distance.
II Back— left to right shoulder (lower part.)	As average; but the maximal distances and minimal distances come too soon, i.e., a displacement of illusion to the right.	As average.	In general, as average; sometimes the upper path seemed to pass over into the lower.	Illusion different with no regularity; also crossing of the paths.
III Upper arm to hip— over volar side of arm, axilla, side.	As average.	As average.	As average.	Same as for back region.
IV Neck	As average	As average	Practically parallel.	Practically parallel.

In the hope of obtaining some indication of the bearing of visualization upon the illusion, we performed a number of experiments with four congenitally blind observers: H. Coover (Co), R. Hudson (H), B. Lowe (L), and H. Stitt (S). All were of high-school age, pupils of the Ohio State Institution for the Blind; the experiments were performed at Columbus. The conditions of the experiment were the same in every respect as those in the Cornell laboratory, except that twelve observations were taken, instead of the usual six. All observers were given preliminary experiments with both single and double points, and with instructions to describe the experience. When they had become accustomed to the situation, the experiments proper were begun. We give a summary of the results in Table XIII.

TABLE XIII

Obs.	Region explored	Distances used (in mm.)	Summary of results
Co.	Volar side of arm-hand (left).	35, 45 40, 40 45, 45 40, 40 35, 35 40, 40	1. Parallel on upper arm, 8 times; diverging, 3 times. 2. Converging at elbow, 5 times; converging to diverging, each, 3 times. 3. Diverging on lower arm, 6 times; parallel, 3 times; converging, 2 times. 4. Diverging on wrist, 7 times; parallel, 4 times. 5. Parallel on hand, 6 times. 6. Parallel on finger, 8 times.
H.	Volar side of arm-hand (left).	35, 45 40, 40 45, 45 40, 40 35, 35 40, 45	1. Parallel on upper arm, 7 times; parallel then converging, 4 times. 2. Converging at elbow, 6 times; parallel, 5 times. 3. Parallel, then converging, 5 times; parallel, 4 times. 4. Parallel on wrist, 6 times; diverging, 6 times. 5. Parallel on hand, 7 times; diverging, 4 times. 6. Parallel on fingers, 10 times.
L.	Volar side of arm-hand (left).	35, 45 40, 40 45, 45 40, 40 35, 35 40, 45	1. Converging on upper arm, 7 times; parallel; 3 times. 2. Converging at elbow; 9 times; diverging; 3 times. 3. Diverging on lower arm, 6 times; converging, 6 times. 4. Diverging on wrist, 6 times; converging, 6 times. 5. Converging on hand, 5 times; diverging, 4 times. 6. Diverging on fingers, 5 times; converging, 4 times.
S.	Volar side of arm-hand (left).	35, 40 40, 30 45, 35 40, 30 30, 35 40, 30	1. Parallel on upper arm, 12 times. 2. Converging at elbow, 6 times; parallel, 4 times. 3. Parallel on lower arm, 6 times; converging and diverging, 2 times each. 4. Parallel on wrist, 7 times; diverging, 3 times; converging, 2 times. 5. Parallel on hand, 6 times; diverging, 5 times; converging, 1. 6. Parallel on fingers, 6 times; diverging 4 times.

If we regard the perception of change of direction and relative distance of the two paths as the essential mark of the illusion, we must conclude that the congenitally blind may experience the illusion, and that visualization is not a necessary component of the perceptive pattern in the normal individual. The differences between the reports of the two types of observer show, nevertheless, that the change in direction is much less frequent in the blind, and that there are greater inconsistencies not only between reports of single observers, but also between observations of different observers. We must suppose that visualization lends greater facility to the perception of relative direction and distance on the skin, and thus to the perception of change in direction of the cutaneous paths.

(e) *Ease of Localization and Variations of Intensity and Clearness, and of Quality, of the Cutaneous Impressions at Various Places.* Lichtenfels, Wundt and Judd, who, as we have already seen, do not accept Weber's explanation of the illusion, suppose that it is conditioned upon differences in degree of distinctness (*Deutlichkeit*) of the impression at various points of its course.¹¹ We have, accordingly, performed experiments in which we asked two observers to report differences of ease of localization, of intensity and clearness, and of quality. These terms were meant to be taken in a rough, everyday sense; we hoped only to find characterizations of experience which might be parallel to the course of the illusion. Observer C, however, was unable to give reports of quality in any other than its attributive sense, and failed, therefore, to find any qualitative differences. A summary of the reports of the two observers will be found in Table XIV.

A comparison of Table XIV with Tables I-IX shows that, as a general rule, a change in ease of localization corresponds with a change in the course of illusion; that less-to-greater ease is correlated with a divergence, and greater-to-less ease with a convergence. Furthermore, an increase in intensity and clearness of the experience is in general correlated with a divergence, and a decrease with a convergence. Finally, in the case of one observer, we frequently find a change in quality correlated with a change in the direction of the illusion. This observer reported also that the clearness of the visual images accompanying the impression varies directly with the clearness of the pressure sensations. There are, however, exceptions to the rules. Observer C found no difference in ease of localization across the breasts, and she found the most

¹¹ See p. 97.

TABLE XIV

OBSERVER Bo.

Region explored	Localization	Intensity and clearness	Quality
I. Ear to ear, over lips.	1. Easiest over lips.	1. Most intense and clear over lips. 2. Then, corner of mouth. 3. Then cheek.	1. "Brighter," "larger" over mouth. Over solid structures a perception of hardness. Over soft structures a perception of softness.
II. Volar side of arm-hand.	1. Easiest on fingers. 2. Then (nearly as easy), palm and wrist. 3. Then, elbow-joint. 4. Then, lower part of forearm. 5. Then, upper part of forearm. 6. Then upper arm.	1. In general, most intense and clear on elbow-joint, beginning of hands, transition from hand, to fingers; and 2. Less intense and clear on arm than hand. 3. Particularly clear at bumpy places and elbow-joint.	1. "Granular, thick" on elbow-joint ("like knee-joint"). 2. "Big, granular" on hand, wrist ("like ball of foot"). 3. "Diffuse, flat, thin," on upper arm ("like that on upper leg"). 4. Quality intermediate between "1" and "3" on forearm.
III. Dorsal side of leg,—near top of upper to middle of lower.	1. Easiest on knee-joint. 2. Then, calf. 2. Then, upper leg.	1. Most intense and clear on knee-joint. 2. Then, lower leg. 3. Then, upper leg.	1. "Granular, thick" on knee-joint. 2. "Diffuse, flat" on upper leg. 3. Quality intermediate between "1" and "2" lower leg.
IV. Dorsal side of leg,—middle of lower to toes.	1. Easy, from ankle to instep. 2. Difficult on leg and near instep.	1. Most intense and clear on sole. 2. Then, heel (nearly equal to "1"). 3. Then, leg.	1. "Much bigger, more granular" on sole and more apt to set up tickle. 2. Then, on leg.

TABLE XIV—*Continued*

OBSERVER C

Region explored	Localization	Intensity and clearness
I. Across breasts.	No differences.	1. Most intense and clear on sternum. 2. Then, sides. 3. Then, breasts.
II. Across back—left to right shoulder (lower part).	Easy all the way.	Doubtfully the same all the way across.
III. Upper arm to hip—over volar side of arm, axilla, side.	1. Easiest on arm. 2. Then, near wrist. 3. Least easy at end of axilla.	1. Most intense and clear on arm. 2. Then, sides. 3. Then, axilla.
IV. Neck.	1. Easiest at vertebral prominence. 2. Then, Adam's apple. 3. Then, side.	1. Most intense and clear at vertebral prominence. 2. Gradually less intense and clear to sides. 3. Same across ventral part.

intense and clear experience on the sternum (where the illusion shows a convergence) and a less clear impression on the breasts (where the illusion shows a divergence). Moreover, in the region across the back, this observer found no difference in ease of localization and in degree of clearness at any point in the illusion. Taking the results as a whole, however, the correlation of ease of localization and degree of intensity and clearness with change in the direction of the paths is about the same as the correlation of the latter with change in degree of sensitivity. The issue between Wundt and Weber must, therefore, be settled on other grounds. We reserve the discussion of this point until we come to consider our results as a whole.

(f) *Racial Differences.* We undertook some experiments with two colored observers, the one (Ca) a negress, the other (M) a mulatto. We explored the same regions as those chosen for more detailed study in our other experiments; and we employed the same procedure throughout, except that we doubled the number of observations for a region. Despite the fact that we gave preliminary series before the experiments proper began, the results were not satisfactory. Not only do the reports differ materially from those of other observers (with the exception of the ear-to-lip illusion), but there is also so little uniformity that a conclusion regarding racial differences is impossible. We append, however, in Table XV sample results for two regions for each observer.

TABLE XV
OBSERVER CA.

Region	Distances	Summary of results
Ear to ear over lips.	30, 30, 25, 20, 25, 30, 30, 25, 30, 25, 30, 25	1. Parallel to corner of lips but converging just at corner, 4 times. 2. Diverging to centre of lips. 3. Parallel to ear, but 3 times diverging toward the ear.
Volar side of arm-hand to finger-tips.	40, 45, 35, 40, 35, 40, 40, 45, 40, 35, 40, 45	1. Parallel on upper arm. 2. Converging at elbow. 3. Diverging halfway to wrist. 4. Converging to near wrist. 5. Diverging over wrist to palm. 6. Converging from palm to finger-tips 7 times, diverging 3 times, parallel 2 times.

OBSERVER M.

Ear to ear over lips.	30, 25, 20, 35, 30, 30, 25, 30, 25, 35, 30, 25.	1. Parallel at beginning. 2. Diverging on cheek. 3. Then converging to corner of lips. 4. Diverging to centre of lips. Illusion in reverse order on other side.
Volar side of arm-hand to finger-tips.	35, 40, 35, 30, 40, 40, 35, 40, 35, 30, 35, 40	1. Usually parallel on upper arm either for a short distance, or to elbow, or to beyond elbow. If parallel only part of the distance, then converging to elbow. Sometimes diverging on upper arm. 2. Diverging over elbow to center of forearm; only once converging at elbow joint. 3. Then, converging. 4. Then diverging over wrist. 5. Converging over base of hand. 6. Diverging over palm. 7. Converging at mounds. 8. Parallel, converging, or diverging over fingers.

C. *Summary of Qualitative Results*

We have found (1) that Weber's illusion occurs in some form in most regions of the body, and that any one form is fairly constant for normal observers. (2) In our study of the various conditions of the illusion we have found (*a*) that there is a high correlation between change in direction of the paths and degree of sensitivity as measured by Weber and Vierordt; (*b*) that the characteristic convergence and divergence of the paths do not appear unless the movement of the stimulus is continuous; (*c*) that rates of movement above 12.5 and below 3.13 cm. per sec. are not adequate to the illusion for all observers; (*d*) that congenitally blind individuals may experience the illusion, so that the visualization which is common for normal observers is not a necessary component of the perceptive pattern; (*e*) that there is a high correlation between places of change in the illusion and ease of localization and variation of intensity and clearness of the cutaneous impressions at these places; and (*f*) that experiments with two observers of the negro race do not admit of any conclusion with regard to racial difference. Since in our quantitative study we shall find additional facts of importance for an understanding of the illusion, we shall defer a general discussion until we have considered the quantitative results.

III. QUANTITATIVE EXPERIMENTS

A. Introduction. The second part of our investigation was a quantitative study of the illusion by the method of equivalents. We sought to discover whether the subjective equation of two cutaneous extents, at places where change of direction in the illusion had been reported, would yield results that could be correlated with the direction of change in the illusion as qualitatively described. There is, it is true, no guarantee that the attitude of judging the relative magnitudes of two cutaneous extents is the same as that of observing relative changes in direction of two moving paths. But, on the other hand, there is no guarantee that the two attitudes are not similar. We ought, therefore, to gain further insight into the psychology of the illusion, regardless of the positive or negative outcome of our quantitative results.

B. Method. The form of the method employed was that laid down by Titchener.¹² As a rule, five points (A, B, C, D, E) were selected, every one of which represented a place of change in the illusion. A standard distance was chosen which was supraliminal for the region.

¹² E. B. Titchener, *Experimental Psychology*, 1905, i, 77 ff; ii, 187 ff.

This standard was first placed at A, and the equivalent values were found for AB, AC, AD, AE. This group we shall call the A group. We then took the equivalent value for B, and employed it as a standard in the B group; *i.e.*, we obtained the equivalent values for BC, BD, BE. We then took the value for C, found in the A group, and determined the equivalent values for CD and CE. Finally, we took the value for D found in the A group, and obtained the equivalent values for DE. All of the standards except the first were taken from the first space-order. Each time-order contained ten series, five ascending and five descending, so that each space-order contained in all twenty series, making forty series in the total experiment. The instrument employed was the Griesbach aesthesiometer with the same points of hard rubber and with the same amount of pressure as in our qualitative experiments. At the beginning of every series there were two signals, 'ready,' and 'now,' only one of these, 'now,' was used for the applications of the stimulus within a series. The interval between the 'ready' and 'now' was two sec.; the duration of a stimulation, one sec.; the interval between stimulations, one sec.; and that between series, about four secs.

C. The Regions Examined. (1) *From Lips to Ear.* Since the course of the illusion was the same on both sides of the face, we applied the method of equivalents to the left side only. According to our plan, the following places were chosen: A, center of lips; B, half-way between the centre and corner of lips; C, corner of lips; D, half-way between corner and ear; E, 1 cm. from ear. The observers for this region were E. G. Boring (B) and Miss F. A. Bean (Be). (2) *From Top of Upper-arm to Finger Tips (volar side).* The places of change were: A, upper-arm, two-thirds distance from axilla to elbow; B, elbow-joint; C, wrist; D, palm (near mounds); E, finger-tips. In working on the fingers, when it was impossible to use large separations of the points on the two middle fingers, we had recourse to the first and third fingers. The standard distance was 40 mm. (for M, 35 mm.). There were five observers, B, Bo, Ca, D and M. (3) *Volar Side of Upper Arm, Axilla and Side to Hip.* Only four places were chosen in this region: A, upper arm (11 cm. above elbow); B, axilla; C, ribs (16 cm. from axilla); D, waist (10 cm. below C). The observers were Miss E. Alspach (A) and E. The latter, however, completed only the A group. The standard distance was 55 mm. (4) *From Sternum over Left Side of Trunk, Shoulder to Spine.* The five places were: A, sternum; B, middle of left breast; C, left side; D, shoulder, one-half distance between the side and spine; E, spine. The observers were C and W. S. Foster (F). The standard distance was 55 mm. (5) *Dorsal Side of Leg-foot, Upper Leg to Heel, over Sole to Toes.* The points selected were: A, upper leg, two-thirds distance from knee to buttocks; B, knee-joint; C, lower leg (15 cm. from knee); D, near ankle (11 cm. from tip of heel); E, sole of foot (5 cm. from the first toe). The observers were A and E. The standard distance for A was 55 mm., for E 70 mm. (55 mm. was too small a distance to give a perception of two points).

D. The Results. In Tables XVI-XX we give the equivalence ratios for every point examined in every group of the five regions. We also give the principal errors for each of the two space-orders, and the two time-errors for each of the two space-orders. The former is the difference between the

standard and the average of the two equivalent values found for each time-order. This value may, therefore, be taken as the measure of the illusion in relation to the standard of its group. In these errors the minus sign means that the equivalent value was less than the standard; in the time-errors the same sign means that the value of the first is less than that of the second time-order.

In Table XXI we give the quotients not only of all ratios found by experiment in every group (first space order), but also those computed from the ratios of earlier groups. *E.g.*, in the B group the computed value (C) of b/c is the reciprocal of a/b over b/c of the A group. In the C group there are two computed values, the first from the A, the second from the B group. The degree of approximation of the computed to the found quotients for any ratio offers a measure of the reliability both of the observer and of the method.

TABLE XVI
EQUIVALENCE FOR FIVE POINTS—LIPS TO EAR

Observer B.	Principal errors		Time errors	
	I	II	I	II
a and b 30.0 : 29.6 :: 28.9 : 30.0	-0.4	-1.1	-0.7	-1.1
a and c 30.0 : 31.2 :: 28.6 : 30.0	+1.2	-1.4	-2.5	-0.7
a and d 30.0 : 38.8 :: 20.4 : 30.0	+8.8	-9.6	-0.1	-0.6
a and e 30.0 : 36.7 :: 21.8 : 30.0	+6.7	-8.2	-1.4	-2.2
b and c 29.6 : 31.1 :: 26.7 : 29.6	+1.5	-2.9	-2.8	-0.9
b and d 29.6 : 39.3 :: 16.1 : 29.6	+8.2	-13.5	-0.5	-1.35
b and e 29.6 : 37.1 :: 16.3 : 29.6	+7.5	-13.3	-0.5	-0.2
c and d 31.2 : 36.7 :: 22.3 : 31.2	+5.5	-8.65	-1.1	+1.5
c and e 31.2 : 35.2 :: 23.5 : 31.2	+4.0	-7.7	-1.0	-0.9
d and e 38.8 : 38.5 :: 36.9 : 38.8	-0.25	-1.85	-0.35	-0.95
Observer Be.				
a and b 30.0 : 31.7 :: 27.7 : 30.0	+1.75	-2.3	-0.45	+1.0
a and c 30.0 : 34.3 :: 28.4 : 30.0	+4.35	-1.6	-2.15	-1.9
a and d 30.0 : 37.0 :: 17.6 : 30.0	+7.0	-12.4	+0.85	-1.4
a and e 30.0 : 40.6 :: 17.9 : 30.0	+10.6	-12.1	-0.55	0.0
b and c 31.7 : 34.4 :: 24.2 : 31.7	+2.6	-7.5	-0.85	+0.5
b and d 31.7 : 39.5 :: 16.9 : 31.7	+2.7	-14.9	-1.0	+0.12
b and e 31.7 : 43.4 :: 20.4 : 31.7	+11.6	-11.4	-0.67	-1.6
c and d 34.3 : 45.4 :: 23.5 : 34.3	+11.0	-10.8	-1.15	-1.2
c and e 34.3 : 43.5 :: 21.5 : 34.3	+9.1	-12.8	-1.0	-2.25
d and e 37.0 : 36.4 :: 39.5 : 37.0	-0.67	+2.45	-0.31	-1.75

(Only four series in a time-order for groups B, C, and D.)

TABLE XVII
EQUIVALENCE FOR FIVE POINTS—VOLAR SIDE OF ARM-HAND

Observer Bo.		Principal errors		Time errors	
		I	II	I	II
a and b	40.0 : 45.0 :: 33.4 : 40.0	+5.0	—6.5	—2.7	—2.85
a and c	40.0 : 29.4 :: 51.7 : 40.0	—10.55	+11.7	—3.6	—5.85
a and d	40.0 : 27.2 :: 51.2 : 40.0	—12.8	+11.2	—2.4	—1.05
a and e	40.0 : 22.2 :: 52.4 : 40.0	—17.7	+12.4	—1.0	—2.3
b and c	45.0 : 32.6 :: 62.0 : 45.0	—12.4	+17.0	—0.1	—0.25
b and d	45.0 : 23.5 :: 56.2 : 45.0	—21.5	+20.2	—1.5	—1.25
b and e	45.0 : 13.4 :: 57.7 : 45.0	—13.4	+12.7	—0.1	—1.25
c and d	29.4 : 29.4 :: 30.1 : 29.4	0.00	+0.7	—0.85	—2.12
c and e	29.4 : 27.1 :: 36.1 : 29.4	—2.32	+6.7	—0.6	—1.37
d and e	27.2 : 19.7 :: 32.4 : 27.2	—7.45	+5.2	—0.5	+0.37
Observer Ca.					
a and b	40.0 : 44.1 :: 37.0 : 40.0	+4.1	—2.95	0.00	+0.55
a and c	40.0 : 29.1 :: 50.2 : 40.0	—10.9	+10.2	—0.12	—1.1
a and d	40.0 : 15.4 :: 53.1 : 40.0	—15.4	+13.1	—3.5	—0.5
a and e	40.0 : 13.6 :: 53.9 : 40.0	—13.6	+13.9	—0.45	—1.35
b and c	44.1 : 24.9 :: 58.2 : 44.1	—19.1	+14.1	+0.45	+1.65
b and d	44.1 : 20.1 :: 54.3 : 44.1	—24.0	+10.2	+2.8	+1.0
b and e	44.1 : 25.5 :: 54.0 : 44.1	—18.6	+9.9	—1.35	—0.25
c and d	29.1 : 33.7 :: 22.3 : 29.1	+4.6	—6.7	—1.9	—0.65
c and e	29.1 : 23.9 :: 34.6 : 29.1	—5.2	+5.5	+0.3	—1.65
d and e	24.6 : 18.1 :: 32.4 : 24.6	—6.4	+7.8	+0.95	—1.45
Observer D.					
a and b	40.0 : 37.0 :: 40.1 : 40.0	—3.0	+0.1	—3.2	—1.0
a and c	40.0 : 21.7 :: 39.8 : 40.0	—19.3	+0.1	—2.3	—4.4
a and d	40.0 : 26.9 :: 45.5 : 40.0	—13.1	+4.45	—5.0	—2.5
a and e	40.0 : 15.5 :: 46.3 : 40.0	—25.5	+3.6	—1.4	—1.85
b and c	37.0 : 26.7 :: 55.5 : 37.0	—10.25	+18.3	—0.35	—1.55
b and d	37.0 : 23.2 :: 58.6 : 37.0	—13.8	+21.6	+0.05	—0.3
b and e	37.0 : 17.0 :: 51.7 : 37.0	—20.0	+14.7	—1.8	—1.4
c and d	21.7 : 18.8 :: 24.5 : 21.7	—2.9	+2.8	0.00	+0.05
c and e	21.7 : 12.1 :: 31.8 : 21.7	—9.6	+10.1	—0.6	—1.1
d and e	15.5 : 13.8 :: 23.1 : 15.5	—1.7	+7.6	—1.0	—0.9

TABLE XVII—*Continued*
EQUIVALENCE FOR FIVE POINTS—VOLAR SIDE OF ARM-HAND

Observer B.					
a and b	40.0 : 46.9 :: 33.7 : 40.0	+6.95	—6.25	—3.15	—0.85
a and c	40.0 : 22.6 :: 51.0 : 40.0	—17.4	+11.0	—1.1	—2.1
a and d	40.0 : 24.6 :: 60.1 : 40.0	—15.3	+20.1	—1.85	—1.85
a and e	40.0 : 19.0 :: 60.2 : 40.0	—21.0	+20.2	—2.7	+0.3
b and c	46.9 : 31.7 :: 61.9 : 46.9	—15.2	+14.9	—1.5	—2.12
b and d	46.9 : 33.1 :: 56.3 : 46.9	—13.8	+9.4	—1.12	—0.12
b and e	46.9 : 22.4 :: 60.0 : 46.9	—24.6	+13.0	—0.6	+0.5
c and d	22.6 : 17.2 :: 31.2 : 22.6	—5.4	+8.6	+0.5	—0.25
c and e	22.6 : 11.5 :: 33.2 : 22.6	—11.1	+10.6	+0.5	+0.75
d and e	24.6 : 23.9 :: 33.7 : 24.6	—0.8	+9.1	—1.37	0.00
Observer M.					
a and b	35.0 : 40.0 :: 30.8 : 35.0	+5.0	—4.2	—0.2	+0.5
a and c	35.0 : 27.4 :: 41.6 : 35.0	—7.6	+6.6	—0.9	—0.55
a and d	35.0 : 24.6 :: 41.1 : 35.0	—10.3	+6.1	—0.65	—2.95
a and e	35.0 : 22.5 :: 47.0 : 35.0	—12.4	+12.0	+1.35	—1.2
b and c	40.0 : 34.0 :: 48.6 : 40.0	—6.0	+8.6	—1.5	—3.35
b and d	40.0 : 29.0 :: 45.7 : 40.0	—10.9	+5.7	—0.45	—1.2
b and e	40.0 : 26.1 :: 54.4 : 40.0	—13.9	+14.4	—2.0	—3.8
c and d	27.4 : 24.8 :: 32.5 : 27.4	—2.6	+5.1	—1.1	—0.9
c and e	27.4 : 16.2 :: 36.3 : 27.4	—11.2	+8.9	—0.3	—0.85
d and e	24.6 : 17.1 :: 29.9 : 24.6	—17.5	+5.2	+1.3	—0.6

TABLE XVIII
EQUIVALENCE FOR FOUR POINTS—VOLAR SIDE OF UPPER ARM,
AXILLA, SIDE

Observer A		Principal errors		Time errors	
		I	II	I	II
a and b	55.0 : 44.0 :: 64.6 : 55.0	—10.9	+9.6	—7.35	—1.15
a and c	55.0 : 36.0 :: 68.4 : 55.0	—19.0	+13.4	0.00	—1.25
a and d	55.0 : 32.5 :: 64.3 : 55.0	—22.4	+9.3	—3.15	—1.45
b and c	44.0 : 53.7 :: 43.4 : 44.0	+9.6	—0.65	—1.6	—0.3
b and d	44.0 : 46.2 :: 34.1 : 44.0	+2.1	—9.9	+1.3	—3.6
c and d	36.0 : 34.0 :: 40.1 : 36.0	—1.9	+4.1	—0.25	—4.6
Observer E.					
a and b	55.0 : 45.38 :: 65.0 : 55.0	—9.62	+10.0	—0.12	—1.00
a and c	55.0 : 24.12 :: 77.13 : 55.0	—30.87	+22.13	—0.85	—1.62
a and d	55.0 : 37.88 :: 62.75 : 55.0	—17.12	+7.75	—3.62	0.00

TABLE XIX
EQUIVALENCE FOR FIVE POINTS—BREAST AND BACK

Observer C.	Principal errors		Time errors	
	I	II	I	II
a and b 55.0 : 57.9 :: 39.8 : 55.0	+2.9	-15.1	-9.3	-5.35
a and c 55.0 : 65.6 :: 41.9 : 55.0	+10.6	-13.0	-14.7	-5.95
a and d 55.0 : 73.8 :: 38.6 : 55.0	+18.8	-16.3	-4.15	-7.45
a and e 55.0 : 74.9 :: 37.2 : 55.0	+19.9	-17.7	+1.15	-4.25
b and c 57.9 : 50.3 :: 83.0 : 57.9	-7.5	+25.1	-4.05	-2.9
b and d 57.9 : 91.5 :: 58.9 : 57.9	+33.6	+1.0	+3.85	-1.5
b and e 57.9 : 69.4 :: 63.2 : 57.9	+11.5	+5.3	-0.85	+0.5
c and d 65.6 : 62.6 :: 78.2 : 65.6	-3.0	+12.5	+4.85	-1.9
c and e 65.6 : 69.6 :: 74.0 : 65.6	+4.0	-8.4	-2.15	-4.5
d and e 73.8 : 88.7 :: 63.2 : 73.8	+14.9	-10.6	+0.75	-1.1
Observer F.				
a and b 55.0 : 37.95 :: 68.55 : 55.00	-17.05	+13.5	+2.25	-0.05
a and c 55.0 : 74.30 :: 42.65 : 55.00	+19.3	-12.35	-2.6	-1.35
b and c 37.9 : 56.40 :: 30.55 : 37.90	+18.45	-7.4	-0.5	+5.55
c and d 74.3 : 48.20 :: 85.55 : 74.30	-3.95	+11.25	+3.5	+8.65
d and e 78.2 : 86.40 :: 76.05 : 78.25	+8.15	-2.20	+1.3	+2.65

TABLE XX
EQUIVALENCE FOR FIVE POINTS—DORSAL SIDE OF LEG-FOOT

Observer A.	Principal errors		Time Errors	
	I	II	I	II
a and b 55.0 : 58.9 :: 63.1 : 55.0	+3.9	+8.15	+0.85	+0.35
a and c 55.0 : 40.3 :: 62.1 : 55.0	-14.6	+7.1	+2.15	-2.2
a and d 55.0 : 18.9	-37.0	.....	+0.75	.....
a and e 55.0 : 26.5 :: 84.3 : 55.0	-28.4	+29.3	-0.65	+0.25
b and c 58.9 : 53.8 :: 64.3 : 58.9	-5.1	+5.3	+2.05	+0.5
b and d 58.9 : 17.4	-41.5	.....	-1.44	.....
b and e 58.9 : 31.3 :: 80.5 : 58.9	-27.6	+21.5	+0.1	-0.5
c and d 40.3 : 25.2	-15.1	.....	+0.65	.....
c and e 40.3 : 37.1 :: 79.5 : 40.3	-3.2	+39.1	+1.05	+1.6
d and e 18.9 : 30.8 : 12.0 : 18.9	+11.9	-6.4	+1.75	+0.35
Observer E.				
a and b 70.0 : 76.2 :: 70.63 : 70.0	+6.25	+0.63	-0.75	-0.90
a and c 70.0 : 44.1 :: 103.20 : 70.0	-25.90	+33.20	-0.12	-1.25
a and d 70.0 : 33.7	-36.25	.....	-1.00	.....
a and e 70.0 : 32.4 :: 116.50 : 70.0	-32.40	+46.50	-2.37	-0.50

TABLE XXI

COMPUTED AND FOUND RATIOS BY GROUPS

Region and observer	A Group				B Group					
	a/b	a/c	a/d	a/e	b/c		b/d		b/e	
	F	F	F	F	C	F	C	F	C	F
1, B.....	1.013	0.961	0.773	0.817	0.947	0.952	0.772	0.753	0.806	0.798
1, Be.....	0.949	0.870	0.810	0.740	0.921	0.930	0.850	0.800	0.918	0.860
2, Bo.....	0.887	1.358	1.469	1.795	1.531	1.374	1.653	1.912	2.022	1.421
2, Ca.....	0.907	1.374	1.625	1.519	1.516	1.765	1.794	2.189	1.624	1.725
2, D.....	1.081	1.840	1.484	2.579	1.710	1.383	1.372	1.594	2.382	2.172
2, B.....	0.853	1.769	1.623	2.125	2.073	1.476	1.925	1.415	2.496	2.097
2, M.....	0.875	1.277	1.421	1.552	1.460	1.176	1.626	1.377	1.779	1.532
3, A.....	1.251	1.529	1.692	.....	1.220	0.822	1.351	0.955	.....	.....
5, A.....	0.934	1.362	2.910	2.033	1.461	1.094	3.120	3.372	2.179	1.881
4, C.....	0.951	0.838	0.745	0.735	0.884	1.152	0.783	0.632	0.773	0.834
3, E.....	1.213	2.280	1.451	.....	.....	.....	.....	.....	.....	.....
5, E.....	0.930	1.580	2.071	1.862	.....	.....	.....	.....	.....	.....

Region 1.—Lips to ear.

2.—Upper arm, forearm to fingers.

3.—Volar side of upper arm, axilla, side to waist.

4.—Breast and back (sternum to spine).

5.—Dorsal side of leg over heel and sole of foot.

TABLE XXI—Continued

COMPUTED AND FOUND RATIOS BY GROUPS—Continued

Region and observer	C Group						D Group			
	c/d			c/e			d/e			
	C	C'	F	C	C'	F	C	C'	C''	F
1, B.....	0.793	0.815	0.851	0.851	0.838	0.887	1.046	1.056	1.041	1.007
1, Be.....	0.779	0.740	0.762	0.850	0.800	0.791	0.921	0.930	1.040	1.020
2, Bo.....	1.388	1.079	1.008	1.321	1.032	1.088	1.228	0.744	1.089	1.378
2, Ca.....	1.183	1.240	0.862	1.071	0.977	1.235	0.902	0.785	1.436	1.482
2, D.....	0.803	1.152	1.154	1.394	1.571	1.791	1.737	1.362	1.552	1.123
2, B.....	0.919	0.959	1.312	1.208	1.421	1.965	1.319	1.483	1.492	1.032
2, M.....	1.113	1.170	1.150	1.218	1.320	1.692	1.093	1.119	1.471	1.442
3, A.....	1.106	1.162	1.162	.....	.....	.....	.....	.....	.....	.....
5, A.....	2.132	3.040	1.595	1.488	1.721	1.081	0.699	0.566	0.679	0.615
4, C.....	0.886	0.548	1.049	0.874	0.723	0.942	0.987	1.316	0.898	0.832

Region 1.—Lips to ear.

2.—Upper arm, forearm to fingers.

3.—Volar side of upper arm, axilla, side to waist.

4.—Breast and back (sternum to spine).

5.—Dorsal side of leg over heel and sole of foot.

The tables show the summaries of more than 4,000 single determinations. As data, they are to be judged by the principal errors, the time-errors, and the consistency of computed to found ratios. The differences between the absolute magnitudes of the ratios of individual observers are not, for us, especially significant; we shall be interested rather in the course of the relative magnitudes. Theoretically, the principal errors of the first and second space-orders should approximate to each other with change of sign. As a rule, they are in fact of the same order; the exceptions are not numerous, and save in one instance do not seriously mar the significance of the results.

This one case is found in Table XVII. Here D in group A gives a *minus* value for the first principal error, whereas all other observers in this region give a *plus*. The three remaining values of the group are very large, whereas the corresponding values of the second space-order are very small; and we therefore suspect that the experimenter herself was at fault, that she set the standard distance on the instrument at 35 mm. (the standard for M below), and recorded it as 40. If this change were made the *minus* would become a *plus*,¹³ and the two principal errors would balance each other properly. In our later treatment of these results we have, nevertheless, left the values as they stand. As regards the opposition of signs in the principal errors, there are only six instances where the two are of the same sign. In two of these (Tables XVI, Obs. B), the values at fault are within 0.4 mm. of equality and are therefore negligible; two of the others (Table XX) were given by different observers for the same pair of points, and are probably due to the difficulties of perception.

An examination of the time-errors shows that, in general, the variables of the first are less than those of the second time-order: when the standard comes first, the variable is judged as *smaller* than when the variable comes first.

If the judgment of the variable were *easier* when the standard comes first, we should expect the m.v. of the various series to be smaller in the first time-order. We have compared the two sets of m.v. for the five observers in the region of the fore-arm, and we find that the percentages of cases in which the m.v. of the first time-order is less are 70, 60, 30, 65, 65. Since we should expect them to be smaller in 50% of the cases, some other factor is apparently at work.

Turning now to the ratios themselves, we find that they speak even more positively for the reliability of our observers. When it is recalled that the computed ratios are based upon found values, and that in the C and D groups there are two and three computed values, the approximation of these to the found values in these groups must be regarded as in general of a high order. There are, of course, exceptions. The

¹³ See D's description of the illusion, Table VII, in which he reports a *convergence* at the elbow.

localization and the judgment of extent are much more difficult in some regions than in others. And some of our observers had had little experience in psychological observation before they came to our experiment. Occasional defects are, therefore, to be expected.

(a) *The Equivalence Ratios as Measures of Sensitivity and of the Illusion.* If we may assume that all other factors are equal, then when an equivalent value is equal to the standard, the result should mean equal sensitivity; if greater, it should mean less, and if less, greater sensitivity. Turning to Table XVI, we find the following values for the five points of the A group (1st space-order), for the two observers

	B	Be
A. Center of lips.....	30	30
B. Half-way to corner.....	29.6	31.7
C. Corner of lips.....	31.2	34.3
D. Half-way to ear.....	38.8	37.0
E. 1 cm. from ear.....	36.7	40.6

It is clear that from the center of the lips to the ear there is, for Be, a gradual increase in magnitude of the equivalent values. For B, on the other hand, the curve is not quite so pronounced. The value for point-B is probably equal to the standard (the difference, -4 mm., is much below the m.v.); and the value for point-E shows a decrease in magnitude over point-D but an increase over the values for A, B, and C. When, however, a direct comparison of D and E is made (in D group), it will be seen that the ratio of the two is within 0.25 mm. of equality. If now we turn to Weber's and Vierordt's description of the relative sensitivity of points in this region, as measured by the two-point limen (Table X, p. 94), we find it to be progressively less. We thus have a first correlation. If, again, we turn to the description of the illusion (Tables I and VI), we find two slightly different accounts: for G, Be and J, a convergence of the paths from center to corner of lips and from that point a convergence to the ear; for Bo paths parallel from corner of lips to ear. Since, as we have already seen (p. 97), a convergence of paths corresponds with a decrease in sensitivity, the equivalent values for Be are, in a sense, measures of the illusion as reported by Weber, G, Be, and J; while B's values are, perhaps, measures of the illusion as reported by Bo.

We obtain a similar result if we take the equivalent values for the fore-arm. Instead, however, of comparing separately the results of the five observers, we will average the values for all observers at every point of the A group and correlate these averages with differences in sensitivity and with the illusion.

A. $\frac{1}{3}$ of distance above elbow.....	40
B. Elbow	43.6 ± 2.8
C. Wrist	27.0 ± 3.9
D. Palm	24.7 ± 3.8
E. Finger tips	19.5 ± 3.8

The general curve of sensitivity is unmistakable; there is first a decrease to the elbow, then an increase to the finger tips. The only question concerns the significance of the difference between wrist and

palm in view of the size of the m.v. Let us, however, turn to the description of the illusion. We find its course described first as parallel, then converging at elbow, then diverging at wrist, then slightly converging at palm and finally diverging or parallel to finger-tips. The single discrepancy between the two sets of results is at the palm; here, according to the averages, we should have a slight divergence or parallelism instead of convergence. The obvious conclusion, supported by the size of the m.v., points to individual differences which are masked by the averages. D, in fact, shows greater sensitivity at the elbow and thus a divergence; and both D and M show a decrease in sensitivity at the palm and so a convergence. All other observers show less sensitivity at the elbow and greater at the palm.

It would, perhaps, be fairer both to the equivalent values and to the illusion if (1) instead of taking the equivalences to the standard of the A group we take those to every standard of the various groups, and if (2) instead of selecting differences between standard and equivalent we take their quotients as measures of sensitivity. If, *e.g.*, the ratio a/b equals 1, the sensitivity for the two points is equal; if again, a/b is less than 1, then the sensitivity of a is less, and if greater then the sensitivity of a is greater than that of b . Turning then to the table of quotients, we take the 'found' values for a/b of A group, b/c of B group, c/d of C group, and d/e of D. group, for every one of the five observers, and average them; we obtain the following results:

elbow	a/b	$0.92c \pm .063$	= less sensitivity = convergence
wrist	b/c	$1.435 \pm .148$	= greater sensitivity = divergence
palm	c/d	$1.097 \pm .130$	= slightly greater = divergence or parallel
finger-tips	d/e	$1.291 \pm .171$	= greater sensitivity = divergence

Aside from the critical point at the palm, the correlation both for sensitivity and for the illusion still holds. As regards the palm, the size of the m.v. again points to equal sensitivity with the wrist. In this connection it may be recalled that, when we compared the course of the illusion with measures of sensitivity as given by Weber and Vierordt (p. 97), we found that, where the sensitivity of two points is approximately the same, there the course of the illusion may be described as converging, parallel, or diverging. The change in direction is always slight, however, and may well be due to secondary factors. There is one other slight discrepancy in the above averages, namely, the size of the ratio for the finger-tips. Since the illusion is frequently parallel at this point, the value is larger than we should expect. The reason is that, when the standard (or variable) distance was too large to go on the two middle fingers, it was placed on the first and third fingers.

The values for two of the three remaining regions give similar results. In that of upper arm, axilla, ribs, and waist, the two observers agree in giving values that show correlation both in sensitivity and in change of direction of the paths for all points except the waist. At this latter point, E shows a decided decrease in sensitivity and convergence, whereas A shows a slight increase and divergence.¹⁴ In the leg-foot region the two observers give results that correspond with the illusion throughout. Below the knee the divergence represented by the equivalent values is much greater than it was reported

¹⁴ See Table V, where it is shown that the author found a convergence and Weber a divergence at this region.

to be in the illusion, since the paths were occasionally reported as parallel; otherwise there is complete correspondence. The values for the breast-back region are less satisfactory. C reports a decrease in sensitivity for the points sternum-nipple, whereas in the illusion she reports divergence of the paths. For the next point (side of breast) in the A group she gives a decrease in sensitivity, as we should expect, but in the B group she reverses this result. F, on the other hand, conforms to the illusion as described; *i. e.*, an increase in sensitivity from sternum to nipple, a decrease to side of breast, an increase to shoulder, and a decrease from shoulder to spine. Unfortunately, the experiment with F was not completed in detail, so that we are unable to work out the quotients of the various groups. The results of C are readily explained from her reports. She not only found it much more difficult to localise the two points than in the qualitative experiments, but she also frequently reported the presence of three or more pressure sensations instead of two, and in the latter case she chose the two that were 'most distinct' upon which to base her judgment.

In what sense, we may now ask, are the equivalent values measures of the illusion? In answering this question two facts should be kept in mind. First, we have individual differences; all investigators have agreed that there are large individual differences in sensitivity as measured by the two-point limen, and our observers have shown individual differences in the magnitude of the equivalent values. We have also found individual variations in descriptions of the illusion. Secondly, we have no way of directly comparing the relative magnitude of the equivalent value at a point and that of the separation of the two paths at that point. We have only occasional observations volunteered by the observers, and our study of the objective data, upon which to base a conclusion. We may say, then, that since at times our observers have reported the relative magnitude of the extent under the one attitude as sometimes larger and sometimes smaller than that under the other attitude, and since we have found a high correlation between equivalent values and the course of the illusion, the former is the measure of the latter very much as a smoothed curve is the measure of a curve plotted by points. In support of this analogy, it may be said that we never find the course of the paths making abrupt changes in direction; even where the convergence or divergence is described as 'quick,' it is always 'smooth.' The analogy must not, however, be taken too literally; the equivalents actually measure the illusion inversely; the plotted curve should, therefore, be reversed; and even then the smoothed curve would represent only one of the two paths.

IV. CONCLUSION: THE PSYCHOLOGY OF THE ILLUSION

Psychologically, the illusion is a perception of two cutaneous extents whose relative locality and direction change in the perception's course. This change in direction, or in distance between the two extents, is the characteristic feature of the perception. The conditions of the experience are not simple; but the results of our study seem to show that the essential factors are two in number: (1) differences in sensitivity of the cutaneous surface, and (2) continuous movement of a two-point stimulus. The influence of the former

is evidenced by the high correlation between course of the paths and degree of sensitivity as measured by the two-point limen, and also by our own correlation between equivalence ratios and sensitivity on the one hand and course of the paths on the other. The importance of the second factor is shown by the fact that with discontinuous movement the illusion is absent. In accepting these two as primary, we necessarily disallow other factors which have been thought to condition the illusion. Since the congenitally blind individual may have the perception, we cannot regard visualization as an essential, although in the normal individual it is a frequent component of the experience. We cannot either accept the view that relative ease of localization and degree of distinctness are necessary conditions of the illusion. In the first place the high correlation between these factors and degrees of sensitivity, and change in course of the paths, implies a single physiological basis; and we may assume that in general the common factor is sensitivity, without assuming that ease of localization and distinctness of impression have no other condition (such as, for example, intensity of stimulus, attention). In the second place we have one instance, at least, where the factor of the moving stimulus cuts across the secondary factors of ease of localization and distinctness, so that the typical illusion occurs in direct opposition to distinctness of impression;¹⁵ and the equivalence ratio obtained with an unmoved stimulus in its turn shows directly the influence of distinctness. Indeed, it seems reasonable to suppose that both distinctness of experience and visualization, when they are independent of sensitivity, are much more frequently operative with an unmoved than with a moved stimulus. We do not believe, therefore, that Judd is justified in arguing from certain equivalence ratios, obtained by Camerer, to the Weber Illusion. Our results seem to show that, on the contrary, these factors function as secondary conditions. In our qualitative experiments the only certain evidence we found for factors other than sensitivity and movement of stimulus was: (1) where the sensitivity of two points is 'approximately the same,' there we may find the paths parallel, or diverging, or converging; (2) where the rate of movement is too slow to give rise to the typical illusion, there we find new intermediate convergences and divergences which are irregular and instable; and (3) the illusion is much more stable and uniform in the normal than in the blind individual. The first two

¹⁵ See the reports of C, pp. 103, 117.

of these results may well have resulted from such conditions as ease of localization, distinctness of impression, visual imagery, etc., when the one or the other of the essential conditions is in abeyance. The third seems to mean that visual imagery serves to stabilize the illusion.¹⁶

V. SUMMARY

1. Weber's illusion has been found on 24 of 42 regions of the body; it occurs more frequently in the longitudinal than in the transverse direction; and, aside from slight individual differences, it is the same in form for all normal observers.

2. The illusion is apparently conditioned upon differences of cutaneous sensitivity, and upon continuous movement of the two-point stimulus. The optimal rate of movement lies between 4 and 12 cm. per sec. Visualization, and distinctness of impression, may occur as secondary conditions; but since the illusion is found with congenitally blind observers, and also in direct opposition to distinctness of impression, neither is an essential factor.

3. Equivalence ratios, determined by the Method of Equivalents for places that correspond with points of change in the illusion, furnish a measure of the illusion in the sense that an increase in an equivalent value corresponds with a convergence, a decrease with a divergence, and an equality with a parallel course of the paths.

¹⁶ We have stated the details and cited the references above, p. 99. M. F. Washburn, Ueber den Einfluss der Gesichtsassociationen auf die Raumwahrnehmung der Haut, *Phil. Stud.*, xi, 1895, 190 ff., had shown that Camerer's equivocal results were due to visualization; a finding which has since been confirmed by Gemelli, *op. cit.*, 133-177, 282. Judd, however, seems to have rejected Washburn's explanation on the ground that not all observers have visual imagery; he accordingly substituted 'Deutlichkeit.'